I. On the Analysis of Optical Spectrum Lines.

II. On the Spectrum of Magnesium.

By

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DISSERTATION

SUBMITTED TO THE BOARD OF UNIVERSITY STUDIES

OF THE JOHNS HOPKINS UNIVERSITY

IN CONFORMITY WITH THE REQUIREMENTS FOR THE

DEGREE OF DOCTOR OF PHILOSOPHY.

Baltimore

1904.

ACKNOWLEDGEMENT.

I wish to express my thanks to Professor J. S. Ames, Professor R. W. Wood, Professor W. J. A. Bliss and Dr. J. E. Whitehead for their instruction and generous advice throughout my entire course. I am also indebted to Professor H. C. Jones and Dr. A. Cohen for their kind instruction in the subordinate subjects.

VITA.

James Barnes was born at Halifax, Nova Scotia, on December [illegible], [illegible]. He received his collegiate education at Dalhousie College graduating with honors in 1899 as Bachelor of Arts. In 1900 he received the degree of Master of Arts and was awarded the 1851 Exhibition Science Scholarship, which was his good fortune to hold for three years. He entered the Johns Hopkins University in 1900 where he has since been pursuing a graduate course in Physics. He spent the summer of 1901 at the University of Chicago. In June 1903 he was appointed a Fellow in Physics in this University.

Part I.

ON THE ANALYSIS OF BRIGHT SPECTRUM LINES.

CONTENTS.

ON THE ANALYSIS OF BRIGHT SPECTRUM LINES.

It is well-known that a change is produced in the wave-length and distribution of light in the lines of the spectrum of metallic vapours and gases when different external conditions are introduced. In most cases these changes were first observed and measured by means of the Rowland grating. Recently, however, these effects have become more readily observable through interference methods, in which the interference-bands are produced with large differences in the paths of the rays.

*Michelson, by aid of his interferometer, resolved the important lines in the radiations of some vapours and gases rendered luminous in vacuum-tubes, and he has studied these radiations in a magnetic field. With his echelon spectroscope he has investigated the same subjects. **Fabry and Perot with their interferometer have investigated the radiations from vapours in the electric arc and in vacuum-

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* Phil. Mag. (5) 31, 338, 1891; 34, 280, 1892.

** Ann de Chim et Phys. 12, 459, 1897; 16, 115 & 2[illegible], 1[illegible]. Astrophys. Journ. 9, 87, 1899.

tubes, and have applied their method for an exact determination of the wave-length of some of the lines in the spectrum of the iron arc and of the dark lines in the sun's spectrum. *Lummer also by an interference method has studied the same radiations, particularly those from mercury, and has separated its prominent lines into many components.

When one compares the results of these investigations the agreement is not very satisfactory. Not only do the number and intensity of the components differ, but the distances between the components do not agree.

The work presented in this paper was undertaken at the suggestion of Professor Ames. The objects of the work were; to study interferometer methods; to obtain, if possible, more consistent results as to the constitution of the lines; and to determine the changes produced in the components under various conditions. Michelson remarks in one of the papers cited, "Still, in many cases, the range of visibility due to slight variations in the conditions shows that the behaviour of each substance must be carefully studied under all possible circumstances of temperature, pressure, strength of current, size and shape of electrodes, diameter of vacuum-tube, etc."

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* Verhdlgn d D. Phys. Ges. 3, 85, 1901.
Phys. Zeit., (3), 8, 172, 1902.

After experimenting a few months with both the Michelson and the Fabry and Perot interferometer the author was fully convinced that the Fabry and Perot method possessed the advantage for the problems in view, since it shows directly the structure of a given radiation by the simple inspection of the system of fringes. Each fringe is in fact a true spectrum of the source and the conditions are the same as those existing in the spectra obtained by the use of a grating having a small number of lines but where the spectra employed are of a very high order. During the progress of the experiments the method proposed by Lummer appeared. While I have not been able to use this method exactly, I used, before I read his paper, one which is very similar to it. This method and results obtained will be described below.

METHOD.

The method involved in this production of interference-fringes will be first briefly considered as it will assist towards a clear conception of the results.

Consider a ray of monochromatic light incident at an angle θ upon two glass plates whose inside surfaces A and B Fig. 1, are slightly silvered and separated from one another a distance D. If the silvered surfaces are parallel, we have

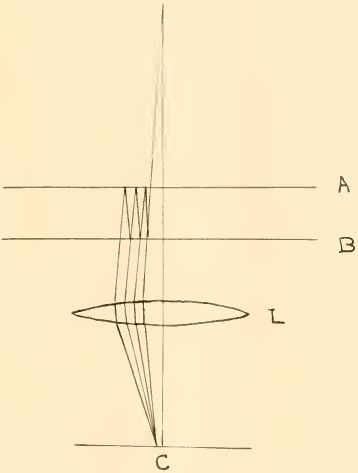

Fig. 1.

on account of the multiple reflections a number of transmitted rays coming from the same source, whose differences of path increase in arithmetical progression. The differences of path with respect to the first are 2D cos θ, 4D cos θ, ... 2 n D cos θ. By means of a lens L these rays are brought to a focus in its focal plane, producing there an interference pattern, bright and dark bands according as 2 D cos θ, 4 D cos θ, etc. are equal to an even or an odd number of half wave-lengths. If we have a symmetrical cone of rays incident upon the plates, the system of fringes obtained on a screen placed in the focal plane of the lens will be concentric circles, having as their centre the point of intersection of the normal from the source upon the plates with the screen, C in the figure. The radii of these circles are equal to f tan θ, where f is the focal length of the lens L.

The intensity of the light at different points in this interference pattern was first worked out by Airy*. His formula is

$$I = \frac{I_o (1 - b^2)^2}{(1 - b^2)^2 + 4 b^2 \sin^2 (\frac{\pi \Delta}{\lambda})},$$

where I_o is the intensity of the incident light transmitted

* Phil. Mag. (3) 2, 20, 1833.

by the silvered surfaces, b the coefficient of reflection of the silvered surfaces, and Δ the difference of path of the rays. We see from this formula that for a given value of b, I will have a maximum when $\frac{2\Delta}{\lambda}$ is an even integer and a minimum when $\frac{2\Delta}{\lambda}$ is an odd integer. Hence the intensity of the bright fringes is I_0, while that of the dark fringes is $I_0\left(\frac{1 - b^2}{1 + b^2}\right)^2$.

Fabry and Perot have calculated the values of I for different values of b and have plotted curves showing the relation between I and Δ for these values of b. The greater the value of b the steeper becomes the intensity curve, so that the interference pattern consists of bright fringes which are very narrow compared with the dark ones (see Plate 1, fig. 1). As we shall see later, the sharper and finer these bright bands are the easier are the radiation analysed and the components measured, thus, while on this account it is advantageous to have b very large by increasing the thickness of the silver film, it must not be so large that I_0, the intensity of the light transmitted, is too small.

Let us now consider the light which is incident upon the plates not to be monochromatic, but to consist of two wave-lengths λ and $\lambda + d\lambda$, then the screen in the focal plane will be covered with two systems of concentric rings. At a

definite separation of the plates let these two systems be in coincidence, then we have the relation

$$\frac{\Delta}{\lambda} = \frac{\Delta}{\lambda + d\lambda} + n,$$

where n is any whole number, or

$$d\lambda = \frac{n\lambda^2}{\Delta - n\lambda}.$$

Since Δ is always large relative to $n\lambda$ we may write

$$d\lambda = \frac{n\lambda^2}{\Delta} = \frac{n\lambda^2}{2D\cos\theta}.$$

Thus by observing the first coincidence of the rings (n = 1) near the centre of the system where θ is so small that we may consider $\cos\theta = 1$, knowing the value of λ, and measuring D, the value of $d\lambda$ can be determined with a very high degree of accuracy. When $d\lambda$ is very small it is not necessary for the determination of its value to separate the plates until the first coincidence occurs, but only till the separation of the rings is clearly visible. When the separation of the systems of rings is, say, one quarter of the distance between consecutive rings of the same radiation, the equation becomes

$$d\lambda = \frac{\lambda^2}{8D}.$$

The resolving power of this method depends upon the distance between the plates and also upon the angle of incidence of the light. The fringes near the centre have thus

the largest resolving power. It is also advantageous to make observations upon the central fringes because their separation is the greatest. This can be shown if we consider the length of the radii of the rings. With the centre of the system a bright ring

$$\Delta = 2\ D = m\,\lambda\ ,$$

where m is an integer; for the first bright fringe out from the centre the difference of path is

$$2\ D\ \cos\theta = (\ m - 1\ )\ \lambda\ ,$$

hence, $\tan\theta = \dfrac{\sqrt{2\ m - 1}}{m - 1}$

and the radius R_1 of the ring is given by the expression

$$R_1 = f\ \tan\theta = f\ \frac{\sqrt{2\ m - 1}}{m - 1}$$

Similarly for the second bright fringe

$$2\ D\ \cos\theta = (\ m - 2\ )\,\lambda$$

hence, $$R_2 = f\ \frac{\sqrt{4\ m - 4}}{m - 2}$$

and so forth for R_3, R_4, etc.

The following table gives the values of R_1 / f, R_2 / f etc. for different values of m .

m	R / f	R_2 / f	R_3 / f	R_4 / f	R_5 / f
1	∞				
2	1.732	∞			
3	1.118	2.828	∞		
4	.882	1.732	3.873	∞	
100	.143	.203	.251	.292	.329

From this table we see that when m = 1, i. e., the difference of path is one wave-length, there is only one interference-band and its radius is infinite, thus the field would be uniformly illuminated. When the difference of path is two wave-lengths there are only two fringes, the first whose radius is 1.732 f, the radius of the second being infinite. For m = 3 there are three fringes. The entire system of bands could only be observed by means of infinite glass plates. We also see that as m gets large, which in practice is generally the case, the lower row in the table shows us that the distance between the first and second ring is much larger than that between the second and third and so on moving out in the system. Thus the separation of the fringes gradually diminishes as we go out from the centre, and hence the advantage of making the observations on the central fringes. This is clearly shown by the figures on the plates which are reproduced from photographs.

This interference method, besides being applied for the analysis of spectrum lines, can be used in the study of the changes in the wave-length of any radiation under the different conditions as indicated above. Any small change will be shown by an increase or decrease in the diameters of these rings, and since very clear photographs can be taken, very accurate measurements on the changes produced can be obtained.

APPARATUS.

After experimenting some time with an instrument which seemed to be particularly sensitive to vibrations, even when every precaution was taken to eliminate extraneous disturbances, a new instrument was constructed. In the construction of this instrument the essential parts sought after were, that the mountings for the plates should be rigid and placed on a massive base so that the bands should be perfectly steady, and that the movable carriage carrying one plate should be capable of very slow uniform motion always remaining parallel to its original position, enabling one to follow clearly the change from one band to another.

In working with a Michelson interferometer as made by Gaertner & Co. the fringes obtained were very steady, even when the instrument rested on a table in the laboratory. I took this instrument stripped it of its mirrors and plates, and using the base, carriage, and screw constructed the apparatus employed.

The apparatus consists of two plane glass plates 3.9cms. by 2.5 cms. and about .6cm. thick, each slightly prismatic in shape; the two faces making with one another an angle between 1" and 2". This prevents the interference bands formed in the plates themselves being superimposed upon those under

observation. Both plates are rigidly mounted in brass frames. One frame can be moved about a vertical axis and the other about a horizontal axis. For very small motions about these axes, so that the silvered surfaces may be made perfectly parallel, two glass tubes were bent into convenient shapes and clamped to the instrument. Their ends resting against a frame are covered with thin sheet rubber. To the other ends are attached long rubber tubes and these connected with a support. By carefully raising or lowering these tubes, which are filled with mercury, the pressure against the frame being therefore varied, very small rotations around either axis are obtained and the surfaces thereby placed in perfect adjustment. Fabry and Perot employed this method using water in their tubes instead of mercury. The carriage containing one of the frames rests upon steel ways, very accurately ground, and is connected by means of a small carriage, placed underneath, to a screw of 1 mm. pitch. The force being thus applied to the carriage in a direction parallel to the motion produces no rocking, as is shown by the fact that the fringes always remained in adjustment during the motion.

To turn the screw two handles are on the instrument, one for rapid and the other for slow motion. A turn of the first corresponds to one turn of the screw. The other is a tangent screw by which it is possible to give the carriage such a

slow motion that the change from one fringe to the next can be easily followed. To both handles were attached graduated discs enabling the distance between the plates to be accurately known.

The whole instrument weighed over 15 kilograms and was placed on a brick pier. The greater part of the observations were taken at night. With this instrument the fringes were always perfectly steady and very long photographic exposures could be made without the least fear of obtaining a blurred image.

Since the radiations from all the sources studied consisted of many wave-lengths it was necessary to employ some arrangement by which the wave-length under consideration could be separated from the others. The following, Fig. 2, was the plan first adopted. S is the source of light. The radiation undergoes an analysis by a Steinheil spectroscope consisting of two flint-glass prisms. The lens L brings the different wave-lengths to a focus on a screen I, which contains a slit. Through this slit the wave-length considered is allowed to pass and passing between the silvered plates forms the interference bands, which are observed by a telescope T or photographed.

The photographic apparatus consisted of a long light-proof box with a circular hole cut in one side. The eyepiece

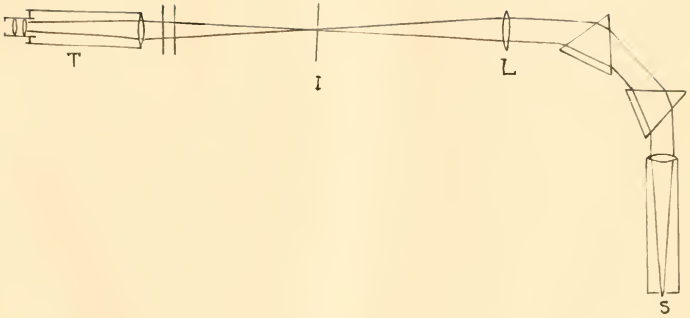

Fig. 2.

of the telescope being removed, the box was placed so that the opening fitted over the end of the telescope. The photographic plate 13 by 3 cms. was in the focus of the objective and mounted so that it could be slid past the opening, and hence a number of exposures made upon one plate.

With the silvered plates illuminated in this way, with divergent light, the entire rings of the interference-bands are observed in the focal plane of the objective as shown on Plate I, fig. 1. The following method, however, was found to be better for the analysis of the radiations. The lens L was removed and the interferometer placed directly behind the prisms so that the parallel light fell upon the silvered plates. With a broad slit in the spectroscope we have in the telescope, focussed for infinity, broad lines corresponding to the lines in the spectrum. These lines are crossed with the interference-bands produced by the plates. By this means the light has been concentrated into a few interference-bands and on this account many of the weaker components appear which cannot be seen with the light divergent as above. Fig. 2 Plate 1. shows this clearly. This photograph is of the bright green mercury radiation and shows three components when the interference-plates are separated 8 mms.

This method possesses also another great advantage. Due to the number of lines in most spectra we have in the field of the telescope at the same time a number of lines containing different kinds of interference-bands depending upon the constitution of the radiation making up each line. This facilitates greatly the analysis of the radiations and we see at once any change that may take place in one or all of the lines through any change of external conditions. The dispersion of the prisms and the magnification of the telescope were such that about half of the spectrum was visible at once. Plate I, figs. 3, 4 and 5 each show the interference-bands due to the two yellow and green lines of mercury vapour taken at the same time with the plates separated at different distances. On account of the broad slit the yellow lines passed through the interference-plates together and hence their interference-bands are superimposed upon one another. The other lines in this region of the spectrum of mercury being of less intensity do not show in the photographs, which were exposed only long enough to get the clearest pictures of the lines considered. The dark green line was quite visible to the eye after passing through the silvered plates. The curvature of the bands in the different lines is of course due to the amount of separation of the plates and to the angle of incidence with which

the radiations are incident upon the interferometer-plates.

For the determination of the scale-reading corresponding to the place where the silvered plates were in contact, a sodium flame or incandescent sodium vapour in a vacuum-tube was employed. The slit of the spectroscope being wide the two D lines were superimposed so that the two radiations together entered the interferometer. The plates were separated until the first coincidence happened, and the readings taken; the operation was repeated several times. Since the difference, d λ, between the sodium lines is known with accuracy from Rowland's tables the distance D between the plates can be calculated from the above equation and thus the zero point obtained. Readings were taken of the successive coincidences as the plates were separated and in this manner the screw was calibrated. If a more accurate calibration is required the two yellow lines of mercury can be used; since their distance apart is about three times that of the D lines, the coincidences occur three times more often in a given distance.

Remarks on Interference-Bands.

Before considering the results I will add some remarks concerning the general character of the interference-bands obtained by this interference method.

When the silvered surfaces are not parallel, but are inclined to one another at a small angle, the fringes obtained are localised in the plates and, as is well known, can be seen by the eye or with a lens focussed on the plates. These fringes, however, can only be obtained when the separation of the plates is very small.

In order to procure clear interference-bands with great differences of paths it is necessary to have the surfaces rigidly parallel. The fringes in this case are seen by the eye, or by means of a telescope focussed for infinity. One of the most important results of this work is that the silvered faces of the plates must be perfectly parallel and the telescope must be focussed for finity to obtain correct results. While this has been noted by former investigators I wish to strongly emphasize the necessity for these adjustments for if these two conditions are not fulfilled all manner of anomalous results may be expected.

On Plate I are shown some photographs of some of the results obtained, if these conditions are not obeyed. Figs. 6 - 12 were all taken with the bright grren line of incandescent mercury vapour in a vacuum-tube. None of the photographs are magnified, the focal length of the objective used was about 15 cms.

The separation of the interference-plates in figs. 1, 6 and 7 was 3 mms. I is where the adjustments are perfect, 6 and 7 show the effect upon the bands when the interference-plates are only a very small degree from being parallel, they being displaced from parallelism by merely raising one of the mercury adjusting tubes less than a centimetre.

In figs. 8 and 9 the plates are separated 0.5mm., in neither case are the plates parallel, in 8 they have an angular separation of over 1". These photographs also show the interference-bands produced _in_ the plates themselves superimposed upon the other.

It is to advantage in the observations to obtain all the light possible, thus a broad source is always employed. The interfering rays from the different points of the source can only produce a clear interference pattern in the focal plane of the objective; in any other plane the bright interference-bands will be wide and hazy. Figs. 10, 11, and 12, illustrate this point. The whole slit is covered with the exception of two points separated 4 mms. from one another in a horizontal direction. Fig. 10 shows the effect when the photographic plate is placed about 1 cm. inside the focus of the objective. Fig. 11 when the plate is placed 2 cms. beyond the focus. Fig. 12 when the plate is exactly in the focal plane; then the fringes

produced by all points of the source are coincident and give clear and sharp interference-fringes. One can easily see that if the whole source were used instead of two points, the bands in 10 and 11 would be wide and hazy, so that if any of the bands due to the components of the radiation were present they would probably be entirely obliterated.

To set the telescope at infinity is easy, but the adjustments necessary to obtain the silvered surfaces parallel are more or less difficult and can only be obtained with practice. The plates are parallel when the fringes are sharp and the illumination equally distributed over the series of rings due to the components.

A REFLECTING INTERFEROMETER.

In the Fabry and Perot interferometer a large amount of light is lost due to reflection from the surface of the silvering in contact with plate A, Fig. 1, so that only a small percentage is transmitted. To eliminate this defect the plates were mounted according to the following Fig. 3. Plate A was heavily silvered and polished on its inside surface and mounted on the carriage of the interferometer as described above. Plate B has its inside surface almost completely silvered, its reflecting power being about .9 and is mounted in the other frame. Light is incident upon the plate A as shown in Fig. 3 and due to multiple reflectio

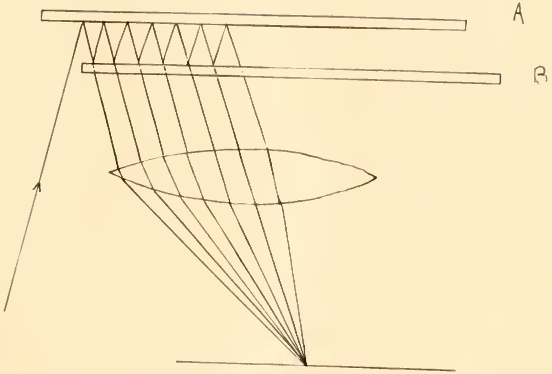

Fig 3.

between the silvered plates we have transmitted a number of rays whose path differences are in arithmetical progression, and the theory of the method is exactly as that sketched above. By this method the bright interference-bands are much brighter than those obtained with the Fabry and Perot method and hence the components more readily seen. On account of the larger incident angle θ of the light upon the plates, the fringes observed are quite a distance from the centre of the system and are therefore close together, causing the necessary adjustments to make the plates parallel more difficult than with the method above where the centre of the system is used. Observations were made with these two methods and the results agreed extremely well.

As mentioned in the introduction a method proposed by Lummer appeared during these experiments. He employs only a long glass plate with parallel faces and passes light into it by means of a prism at such an angle that it emerges at almost the critical angle. The method is very similar to the method above. In Lummer's method, however, since the thickness of a given glass plate is fixed, the positions of the components relative to one another cannot be determined, and if the faces of the plates are not perfectly parallel many anomalous results, as those indicated above, may be obtained.

RESULTS.

On the basis of what has preceded the following results have been obtained. A number of sources were employed, - metallic vapours in vacuum-tubes rendered luminous by the discharge from a large induction-coil, metallic vapours in a Bunsen flame and in an electric arc, and lastly the electric spark between electrodes of the metals. This latter source was found to be very unsatisfactory. Of the many sources tried the bright radiation from mercury vapour was the best for obtaining observations on the changes produced in the compounds by external changes in the conditions. We will thus first consider the results with this source. Great pains were always taken to have perfect adjustments chiefly with respect to the focussing of the telescope and the parallelism of the interference-plates, before any readings were taken.

The vacuum-tube discharge was obtained in a Geissler tube with mercury electrodes of the form suggested by Runge and Paschen*, the capillary of which was placed directly in front of the slit of the spectroscope. The different tubes were connected to a Geryk pump and a pressure gauge, enabling the pressure of the vapour through which the dis-

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* Astrophys. Journ. 15, 238, 1902.

charge passed to be quickly changed from a few millimetres to a fraction of a millimetre.

It is rather difficult to decide what is the most advantageous way to record results, whether to take what appears to be the centre of gravity of the various components constituting the radiation as the position from which to measure wave-lengths, which is the usual way in the measurements of the lines obtained by means of the grating, or to consider the component of the greatest intensity as the standard and record the wave lengths of the other components with reference to this; this method is the one employed by Michelson, and Fabry and Perot. The latter method, nevertheless, is unsatisfactory, for I have found, even in some of the few radiations investigated, that there are two or more bright components whose intensities are equal. For want of a satisfactory standard, and also that the following results may be easily compared with those of the other investigators, their method has, however, been followed. In the cases where the brightest components are of equal intensity one of them has been selected for the standard. In what follows the plus sign indicates that the component has a longer wave-length than the standard, the minus sign the reverse.

The following results were obtained after a long series of observations with a tube whose capillary was 0.5 mm in

diameter and the vapour at a pressure of 1.5 mm. The bright green radiation whose wave-length is 5461 consists of six components; the two brightest having about equal intensities, the one having the longer wave-length will be considered the standard. The other components have the following differences in wave-length and in intensity relative to the one selected.

1.	Standard Component,	Intensity	1
2.	-1.1×10^{-8} mm.,	"	3/4
3.	$-.9$ "	"	1/4
4.	-0.4 "	"	1
5.	$+0.1$ "	"	1/8
6.	$+0.4$ "	"	1/4

Thus there are three components on the side toward the shorter wave-lengths and two towards the larger.

The violet line, 4358, is a triple having slight components on each side of the principal.

1.	Standard Component,	Intensity	1.
2.	-0.5×10^{-8} mm.,	"	1/4
3.	$+0.4$ "	"	1/4

Both the yellow lines have numerous components but they are of very slight intensity so that concordant results were not obtainable.

When a small amount of air was allowed to enter the vacuum-tube till the pressure was about 5 mms. the components of small intensity completely disappeared, the fringes due to the brighter components broadened and their edges became less sharply defined, showing that the atomic vibrations were not so uniform and simple as before. The same effect was noticed with the radiation from a vacuum-tube which had been used some time without any change of pressure. In the case where the pressure is changed through the introduction of air the molecular collisions may be made more frequent, which would naturally interfere with the free vibrations of the atomic systems and so produce a broadening of the bands and cause the less intense fringes to disappear. In the case of an old tube, when the pressure has not changed, there seems to be no other explanation for the observations than that the mercury vapour had become contaminated with gases driven off from the glass by the heat developed in the discharge.

Whether the atomic vibrations in a source are changed on account of the presence of molecules of foreign matter is an open question. Michelson* thinks that the presence of other molscules does not have any appreciable effect except to diminish the visibility. In the case of mercury he ob-

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* Phil. Mag. 34, 280, 1892.

tained quite different visibility curves when the pressure was high to that obtained when the pressure was low. When the mercury was placed in an atmosphere of hydrogen the characteristics of the visibility curves were not changed. My results show, however, that when mercury is placed in the presence of air both in the vacuum-tube discharge and in the arc, which will be described later, the appearance of the interference-bands is clearly changed, which can only be due to a change in the oscillations of the atomic systems. Schuster in a lecture at the Royal Institution in 1881 drew from his results the conclusion " Placing a molecule in an atmosphere of a different nature - without change of temperature - produces the same effect as would be observed in lowering the temperature". In a note to the Astrophysical Journal* he says "Something similar seems to take place as regards pressure for the sodium lines may be obtained wide or narrow according as the atmosphere producing the pressure consists of sodium molecules only or of molecules of a different nature". The results here obtained seem to corroborate those of Schuster.

As being of some importance in this subject I have

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* Astrophys. Journ. 3, 292, 1896.

introduced figs. 14 and 15, Plate II, showing the broad bands of the sodium lines, separated and superimposed, obtained with a sodium flame in air as the source. With sodium in a vacuum-tube these bands are as sharp as those of the mercury fringes on Plate I. Fig. 13 was obtained with the green radiation from mercury in a tube which had been used a considerable time. The separation of the plates was 6 mms. Here not even one component is visible. A comparison of this photograph with that of Fabry and Perot reproduced in the Astrophysical Journal, May, 1901 may interest the reader. This reproduction is of the fringes of the same line with the same separation of plates but shows the components. The figs. 13, 14, 15, Plate II have been magnified about five times. Fig. 16 has not been magnified, and shows how sharp the bands are when the plates are separated 1 cm. Here also the components of the mercury green radiation are invisible.

With tubes containing capillaries whose diameters are greater than 2 mms. the light obtained with an ordinary discharge is not sufficiently intense to show the finer components. The components that can be seen have their edges quite sharp, showing that the vibrations in these tubes are probably the same as in the tubes of smaller capillaries. The finer the capillary the greater the electrical resistance to the discharge and hence a rise in temperature, causing a

brighter light. Temperature is an important factor, for by heating only the capillary of a tube where there is no liquid mercury present and thus producing no noticeable change in the pressure in the vacuum tube, the kinetic energy of the atomic aggregations is increased such that many of the components of small intensity invisible before are now very readily seen.

The number and intensity of the components were the same whether the tube was placed "side on" or "end on", that is whether the discharge was perpendicular or parallel to the propagation of the light through the slit.

The introduction of capacity in parallel with the discharge circuit had an interesting effect. With three large Leyden jars, each gallon jars, the fringes were broadened and the finer components disappeared. The effect appeared in every way analogous to that when the pressure was increased.

The next step was to investigate the radiations from a mercury arc and compare the results with those above. After many trials with different kinds of arcs the following form, Fig. 4, was found the most satisfactory. The arc is between two mercury surfaces. A is an ordinary glass receiver of about 800 cc. capacity. Over the mouth B is sealed a piece of plate-glass; through the rubber stopper C is run a glass

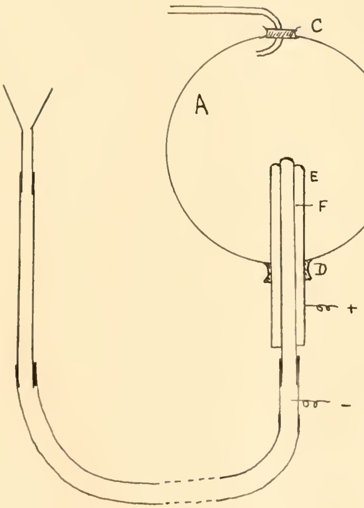

Fig 4.

tube which is connected to the Geryk pump. Through the stopper D is placed an iron tube E of diameter 13 mms., along the axis of this is placed a porcelain tube F of diameter 8 mms. This porcelain tube is connected with a glass tube which in turn is connected with a large rubber tube. The mercury fills the space between the porcelain and iron tubes as well as the porcelain, glass, and rubber tubes attached. The electric poles are placed as shown in the figure. By raising the barometer column until a drop of mercury flows over into E the arc is started. Any further adjustments are easily carried out by raising or lowering the mercury column. Since all the joints were made air-tight the pressure could be varied by means of the pump. Within a few seconds after the arc is started the whole bulb of receiver is covered with a layer of mercury thrown off from the arc, this does not penetrate into the neck so that the glass at B is always clear and the radiation from the arc passes through to the slit of the spectroscope without loss. The whole apparatus may be placed in a cold water bath to keep the joints cool. This was found unnecessary with the apparatus used even when the arc was steadily run as long as ten minutes. Usually 110 volts were employed, the current was varied by means of a rheostat, generally 4 amperes were used.

With the pressure under 5 mms the results were the same as those obtained with vacuum-tubes as given above. Above this pressure it was very difficult to obtain any components and the bands were broad and hazy. This is probably due, as above, to pressure and the presence of a number of molecules of air.

The results obtained with the other metallic vapours and gases are briefly as follows.

Cadmium. Small pieces of metallic cadmium were enclosed in a Geissler tube surrounded by an asbestos jacket; when heated with a Bunsen flame the metal easily vapourized.

The red line 6439 is nearly monochromatic; there is, however, a weak component towards the shorter wave-lengths.

1.	Standard Component,	Intensity	1
2.	$- 0.1 \times 10^{-8}$ mm.,	"	1/5

The green line 5086 is composed of four components the three weaker being on the side towards the larger wave-lengths.

1.	Standard Component,	Intensity	1.
2.	$+ 0.4 \times 10^{-8}$ mm.,	"	1/4
3.	$+ 0.25$ "	"	1/4
4.	$+ 0.1$ "	"	1/8

The blue line 4800 has a component on each side of the

principal.

1.	Standard Component,	Intensity	1.
2.	$+0.6 \times 10^{-8}$ mm.,	"	1/5
3.	-0.4 "	"	1/4

<u>Thallium</u>. A piece of metallic thallium was placed on the end of a platinum wire and held in a Bunsen flame. The only bright radiation was that of the green line, 5439. A doubling of bands occurred when the plates were separated only a few millimetres. With a vacuum-tube radiation, another component was found with wave-length between the principal and first component.

1.	Standard Component,	Intensity	1.
2.	$+1.0 \times 10^{-8}$ mm.	"	3/4
3.	$+0.4$ "	"	1/4

<u>Hydrogen</u>. By the kindness of Dr. Parsons I used one of his tubes containing hydrogen which was specially pure, the pressure being 1 mm. The red line easily breaks up into three components one on each side of the brightest component.

1.	Standard Component,	Intensity.	1
2.	$+0.6 \times 10^{-8}$ mm.,	"	1/4
3.	-0.2×11 "	"	1/8

The green line is very complex, the components are so numerous that observations are very difficult.

The changes in the components due to changes in pressure, size of capillary, capacity in circuit which were examined principally with the mercury radiations were in some cases tried with the other radiations considered and the results were in general the same. The above results with respect to the relative wave-length and intensity of the components under the conditions specified are collected in the following table together with the results of Michelson, and Fabry and Perot upon the same radiations obtained in vacuum-tubes. Michelson's values are taken from the curves given in his paper. His method does not allow the determination as to whether the components have larger or shorter wave-lengths than the standard. The second list of values for the components of the mercury line, λ = 5461, obtained by Fabry and Perot are taken from a paper by *Zeeman.

After the many long and tedious observations together with the study and elimination of the errors which may enter into the results due to imperfect adjustments of the apparatus, the author regrets that he is unable to present a more detailed account of the variations that occur in these component radiations or satellites as they have been called. The changes occur so suddenly on the least change of the surrounding conditions and sometimes even when no changes

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* Astrophys. Journ. 15, 218, 1902.

TABLE.

Michelson.		Fabry & Perot.		Author	
Constitution and Separation x 10 mm	Intensity.	Constitution and Separation. x 10 mm.	Intensity.	Constitution and Separation. x 10 mm.	Intensity.
		Mercury, λ = 5461			
1. Std. Compt.	1	Std. Compt.	1	Std. Compt.	1
2. 1.2	1/10	2. +0.9	1/6	2. - 1.1	3/4
3. 1.0	1/4	3. +0.1	1/3	3. - 0.9	1/4
4. 0.7	1/10	II		4. - 0.4	1
with two weak components near standard.		1. Std. Compt.	1	5. + 0.1	1/8
		2. -2.2	1/2	6 + 0.4	1/4
		3. -0/7	1/4		
		4. -0.5	1/3		
		5. +0.1	1/2		
		6. +0.8	1/3		
		7. +1.3	1/4		
		Mercury, λ = 4358			
1. Std. Compt.	1			1. Std. Compt.	1
2. 1.7	1/10			2. - 0.5	1/4
with two weak components near standard				3. + 0.4	1/4
		Cadmium, λ = 6439			
no components.		no components.		1. StdCompt.	1
				2. -0.1	1/5
		Cadmium, λ = 5086			
1. Std. Compt.	1	1. Std. Compt.	1	1. Std. Compt.	1
2. 0.2	1/5	2. -0.3	1/3	2. +0.4	1/4
				3. +0.2	1/4
				4. +0.1	1/8

Michelson		Fabry & Perot.		Author	
Constitution and Separation x 10 mm	Intensity.	Constitution and Separation x 10 mm.	Intensity.	Constitution and Separation x 10 mm.	Intensity.
Cadmium, λ = 4800					
1. Std.Compt.	1	Std.Compt.	1	1.Std. Compt.	1
2. 1.0	1/8	2. +0.8	1/3	2. +0.6	1/5
		3. -0.8	1/3	3. -0.4	1/4
Thallium, λ = 5439.					
1. Std.Compt.	1	1.Std.Compt.	1	1.Std. Compt.	1
2. 1.2	1/8	2. +1.1	1/2	2. +1.0	3/4
3. 1.0	1/2	3. +0.2	1/2	3. +0.4	1/4
4. 0.2	1/8				
Hydrogen λ = 6563.					
1. Std.Compt.	1			1.Std.Compt.	1
2. 1.4	3/4			2. +0.6	1/4
				3. +0.2	1/8

apparent to the observer were introduced, that only qualitative results of a very general nature can be expressed.

During the observations upon the sharp interference-fringes due to the mercury green radiation in the two cases, when the components were visible as exemplified by the photograph given by Fabry and Perot as referred to above, and when with the same separation of the silvered plates, the components were not present as exemplified by Fig. 13, Plate II, the question arose, - has the change in the conditions given birth to one or more satellites? The sharpness of the fringes in both cases, the unequal change in the intensity of the various components under variable conditions, as is shown when the capillary of a vacuum-tube is heated, and in the fact that the results given in the above table upon the distances between the components are in poor agreement which is probably due to the different circumstances surrounding the radiation, all point to the possibility of the production of satellites. It must not be forgotten, however, that at the separation of the plates necessary to show the presence of the components the interference-bands are very close to one another so that it is impossible in this method for an interference-fringe due to the birth of a satellite to appear without overlapping some part of the in-

terference-fringes of the other components and hence produce a new distribution of light in the interference-pattern which would naturally lead to different results.

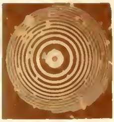
The investigations of the variations in the wave-length and intensity of radiations separated by the grating on account of variation in pressure , electrical condition of the discharge, and the chemical nature of the dielectric surrounding the luminous substance, is at present a very fruitful field. For these changes in these widely separated lines lend themselves to measurement. It is hoped that a method will be found which will more readily show and give measurements of the many changes that occur in radiations whose wave-lengths and hence their frequencies do not differ greatly, so that ultimately some knowledge as to the mechanics of the systems of moving electrons constituting the atom whose periods differ by small amounts relative to those obtainable at present may be obtained. A step in this direction has been made by Lummer. The reproductions in the Ann. d. Phys., 10, p. 473, 1903, show excellently the complicated structure of these bright radiations. The method proposed above, employing longer plates is worthy of a fair trial.

My heartiest thanks are due to the professors and lecturers in Physics in this University, especially Professor Ames and Professor Wood, and also to my fellow students whose kind assistance in word and deed has greatly facilitated these experiments.

Physical Laboratory,

Johns Hopkins University.

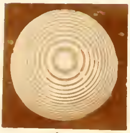
Plate I.



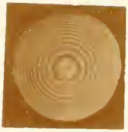
1.

2.

3. 4. 5.

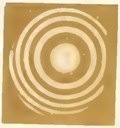


6.



7.

8.



9.

10.

11.

12.

Interference Fringes under Various Conditions

Plate II

13.

14.

15.

16.

Figs. 13 and 16, green mercury line.
Figs. 14 and 15, sodium lines.

PART II.

ON THE SPECTRUM OF MAGNESIUM.

CONTENTS.

On the Spectrum of Magnesium.

Introduction.

The magnesium spectrum is of much interest as it appears in the spectrum of many[1] stars and also on account of its application in the determination of[2] stellar temperatures.

The line λ 4481 appears very strong in the spectra of numerous stars belonging to Vogel's first type, while λ 4352 is very faint or not present. From these facts Scheiner reached the conclusion that on the stars of the first type the temperature of the absorbing layer was approximately that of the electric spark, while on the stars in whose spectrum the line λ 4352 more strongly occurs, the temperature was about that of the electric arc. Just what Scheiner meant by the temperature of the spark is not clear for the words "temperature of the spark" has in itself no meaning according to our present ideas based on the kinetic theory of gases. Recently Hartmann[3] has shown that the presence or absence of these lines is no indication of high or low temperatures, that is, the lines λ 4481 and λ 4352 are not due to temperature,

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(1). H. C. Vogel. Astr. Nachr. No. 3861, 3[illegible], 1903.
(2). H. Kayser. Ibid. 3863, 277, 1903.
(3). Astrophys. Journ. 17, 270, 1903.

but rather to electrical causes.

The so-called spark lines are those which appear in the electric spark produced by a high tension discharge and are rarely present in the arc running under the ordinary voltage and current. The arc lines are those that appear in the arc and are of weak intensity or not visible in the spark discharge.

It was the object of this work to repeat the observations of Hartmann and also to study other conditions which might be found to enhance or diminish the intensity of these lines.

Historical Sketch.

I need only briefly to refer to the work of Liveing and Dewar[1], who first observed the presence of spark lines in the arc produced between thick electrodes of magnesium, when surrounded by air, carbonic acid, ammonia, etc. From their results they threw doubt on the then accepted opinion that the temperature of the spark discharge was much higher than that of the arc. They believed that the production of the "spark lines" was conditioned by the energy of the electric discharge and not by any change in temperature.

This important result led the way for further investigation. Crew[2] found the spark line λ 4481 to be one of the strongest lines in the spectrum obtained with his "rotating" arc. This line was intensified when the arc was surrounded by hydrogen, while the lines belonging to the Kayser and Runge series were unaffected. Porter[3] with the same arc in nitrogen found this line reduced to about one-fifth its intensity in air. Schenck[4] observed that the intensity of the line λ 4481 decreases in the spark spectrum if the elec-

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(1). Proc. Roy. Soc. 44, 241, 1888.
(2). Phil. Mag. (5) 38, 379, 1894,
Astrophys. Journ. 12, 167, 1900.
(3). Astrophys. Journ. 15, 274, 1902.
(4). Ibid. 14, 116, 1901.

trodes are heated to the point of melting. Hartmann[1] and Eberhard observed that the spark line appeared in the spectrum of the arc under water, the effect being analogous to that produced by hydrogen on the arc. Recently Hartmann[2] has been able in the case of magnesium and bismuth to transform the arc spectrum into the spark spectrum without changing in any way the surrounding dielectric, by merely diminishing the strength of the current. From the results of his very careful experiments he has conclusively shown as was believed by Liveing and Dewar that the presence of the line λ4481 is no proof of high temperatures, but is rather due to electro-luminescence.

Apparatus.

A Rowland concave grating of about thirteen feet radius was used and photographs were taken in the first spectrum since in this order it was the most brilliant. Later in the work a smaller grating with radius of 60 cms. was found sufficient for the problems in view.

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(1). Astrophys. Journ. 17, 229, 1903.
(2). " " 17, 270, 1903.

Solid magnesium rods of about 1 cm. diameter were employed as electrodes. These, suitably mounted, were enclosed in a glass vessel of 800 cc capacity and having a long neck, over the end of which was sealed a piece of plate glass. In the two openings in the side of the vessel were placed rubber stoppers conveying the supports for the electrodes and the electrical connections. A glass tube connects with the hydrogen generator and the Geryk exhaust pump. Soon after the arc is started the side of the vessel is covered with a deposit of oxides thrown off from the arc, this, however, does not penetrate into the neck so that the radiation passes through to the slit of the grating without loss. The rubber stoppers allowed the electrodes to be slightly moved without affecting the pressure in the vessel. In this way the electrodes could be brought together to strike the arc. The hydrogen was obtained with an ordinary kit by the action of hydrochloric acid upon granulated zinc. It was passed through sulphuric acid before entering the vessel containing the arc.

The current was obtained from a 110 volt circuit and its strength was varied by resistances consisting of incandescent lamps. When the spark was employed it was produced by an ordinary induction coil.

When the magnesium arc was run in air the electrodes became coated with the oxide, this had to be removed when small current strengths were employed before an arc could be started. As the arc had to be made a great number of times during the exposure, plates were only taken when the air surrounding the arc was at atmospheric pressure, where the magnesium oxide could be easily removed and also at very low pressures when the little oxide formed did not interfere with the striking of the arc whenever required. At other pressures below the atmospheric it was impossible to clean the electrodes without opening the vessel and thereby changing the pressure. As hydrogen does not unite with magnesium, observations could be obtained without difficulty at any pressure.

Results.

After taking a systematic series of photographs of the spectrum of the arc under different current strengths and pressure of surrounding gas, it was found that the intensities of the lines in the first subordinate series λ 3838.4, 3832.5, and 3829.5 and in the second subordinate series λ 5183.8, 5172.8, 5167.5 were practically unaffected. These lines are unaffected in the spark. Thus the intensity of the line λ 5183.8 has

been taken as the standard which is called 10; a line barely visible is given the intensity 1. The following tables contain the results obtained; the pressures are given in millimeters of mercury and the current strengths in amperes.

Arc in Air.

Wave Length of Line.	Pressure.	Intensity when Current Strength is 7.5	5.5	2.0	1.0	.5
4703.2	760	10	10		10	8
(arc line)	1		[illegible]	8	6	4
[illegible]71.3	760	6	6		4	[illegible]
(arc)	1		1	0	0	0
[illegible]	760	0	1		10	15
(spark)	1		10	10	10	10
[illegible].1	760	10	10		10	[illegible]
(arc)	1		5	2	1	1
[illegible]	760	7	[illegible]		[illegible]	[illegible]
(arc)	1		2	1	1	1
[illegible]	760	5	[illegible]		[illegible]	[illegible]
(arc)	1		1	1	[illegible]	0

Arc in Hydrogen.

Wave Length of Line.	Pressure.	Intensity when Current Strength is	
		5.5	0.5
4703.2	760	8	[illegible]
	380	[illegible]	1
4481	760	4	15
	380	[illegible]	15
[illegible].1	760	[illegible]	0
	380	4	0

The other arc lines are omitted from the hydrogen part of table as they do not appear on the plates at any pressure or current strength.

These tables show that all the arc lines are weakened when the strength of the current is diminished both at atmospheric and lower pressures when the dielectric is air or hydrogen. In air the change in intensity is slight. Also, with the same current and pressure, hydrogen diminishes the intensity of the arc lines while the spark line is enhanced, which is in accordance with the results of Crew. It is also seen how the remarkable spark line λ 4481 in air is intensified as the current is decreased, thus confirming the ob-

servations of Hartmann. In both air and hydrogen gases the arc a decrease of the pressure always weakens the arc lines and intensifies the spark lines. It is important to note that the intensity of the line λ 4481 in a vacuum of about 1 mm pressure does not change its intensity with the variation of current throughout the range employed. It is also worth remarking that the plate taken of the spectrum of the spark discharge with an induction coil having a Leyden jar in parallel with secondary was so similar to the one taken of the spectrum of the arc in a vacuum that almost no difference was perceptible. The distance between the electrodes in all the observations was not more, generally less, than a few millimeters. The voltage across electrodes was about forty volts.

With regard to the spectrum of zinc, cadmium and bismuth very few conclusive results were obtained. If a transformation of the arc spectrum into the ~~arc~~ spark spectrum happened, it was much less striking than in the case of magnesium where the steps were easily obtained. The observation of Hartmann that the zinc spark lines λ 4912 and λ 4924 appeared in the arc spectrum on reducing the current to 0.5 ampere was corroborated. It was found that these spark lines made their appearance in the arc when only a trace of

than could be found if the arc were surrounded by air at atmospheric pressure using the same strength of current. In the case of cadmium and bismuth I was unable to satisfy myself of the appearance of the spark lines in the arc in a vacuum.

SUMMARY.

Magnesium. In the arc in air at atmospheric pressure the arc lines are weakened as the strength of the current is diminished, while the spark line λ 4481 is increased in intensity. For all strengths of current the arc lines are weakened as the pressure is decreased and just the reverse is the case with the spark line. The same phenomena occurs in hydrogen but to a more marked degree.

The line λ 4481 when obtained with the arc in a vacuum does not change its intensity with any variation in the current strength.

Zinc. In the arc in air the spark lines λ 4911, and λ 4925 make their appearance when the current was diminished. These lines also appeared very clearly in the arc in a vacuum while they were absent in the arc in air using the same current strength.

In the light of these results nothing need be said regarding the temperature of the arc and the spark since these observations easily fall into line with the only alternative of Hartmann (Astrophys. Journ. 17, 270, 1903). The work of all the above named investigators directly points to the conclusion that the line λ 4481 is due to electrical causes, electroluminescence, rather than to high temperatures.

I do not propose to offer an explanation until further data have been obtained except to say that it will probably rest on the fact that the appearance of the line λ 4481 is associated with the sudden flow of the electrical charge when the arc is made. A word may be said regarding the explanation offered by Hartmann. He says "We may assume that the line 4481 results from the vibrations of particles highly charged with electricity, and therefore it can appear only of reduced intensity, if at all, if such a charge is in any way prevented. Now, as soon as the electrodes are charged by the stronger current there occurs a vigorous vaporizing of the metal, the conductivity of the arc becomes greater and the separated particles take on only very slight charges, so that the vibrations corresponding to the line λ 4481 must always become weaker with increasing current strength". Only

explanation is not clear in so far as it does not seem to agree with the above results. For in the arc in a vacuum the resistance is at any time less than in air at atmospheric pressure and hence according to Hartmann's theory the intensity of the line $\lambda 4481$ should be less or at least equal to its intensity in air at the same current strength. The above results show, however, that the intensity of this line is greatly increased. One observation which bears directly on the cause of the line $\lambda 4481$ is that it appears principally in that portion of the arc near the negative electrode as is shown on Plate III, fig. 2. This photograph was obtained by removing the slit of the spectroscope and placing the arc in its place. For an exposure the arc was only made a second or less; the current was 3 amperes. Another observation of note is that with the electrodes kept free from magnesium oxide and separated from one another a distance of about 3 mm the line $\lambda 4481$ was barely visible, while with a separation of 1 mm and less, the intensity of this line was increased about five times. These results were obtained at atmospheric pressure with a current of 3 amperes.

In conclusion the author wishes to thank Professor Ames for many suggestions made during the work.

Plate III.

— Spectrum of —
Magnesium Arc — —
obtained in a Vacuum.

λ4481

1.

Spectrum showing line λ4481
only at the cathode.

λ4481.

2.